

# **Representation of Dynamic Troposphere-Stratosphere Coupling in CMIP5 models**

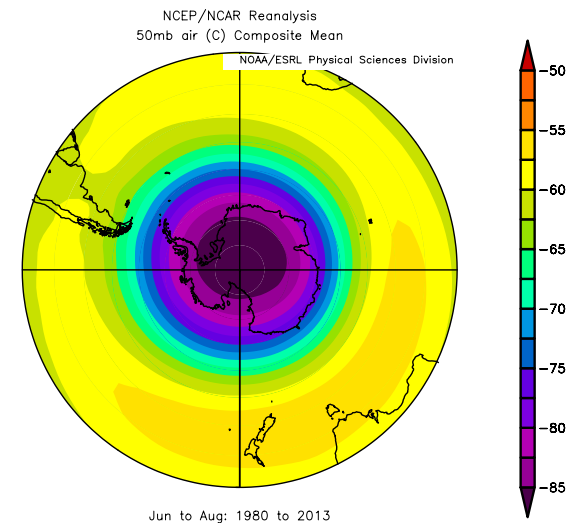
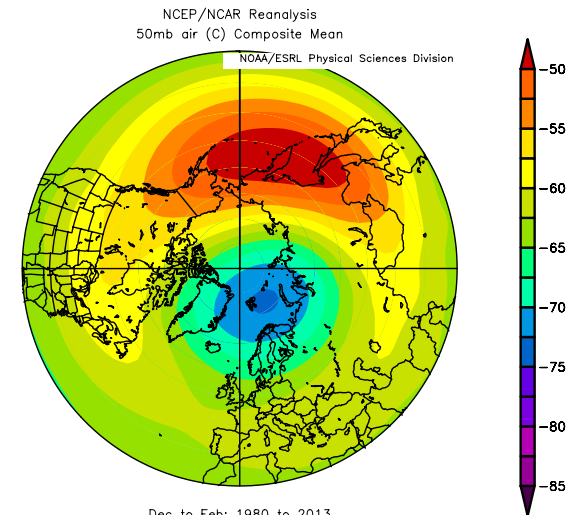
**Judith Perlwitz**

**NOAA/ESRL Physical Sciences Division  
and CIRES/University of Colorado**

Work in collaboration with Tiffany Shaw (University of Chicago)

# Stratosphere-Troposphere Dynamic Coupling

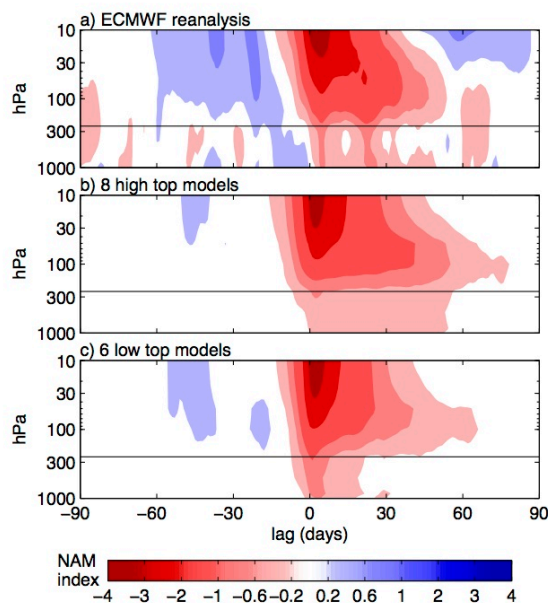
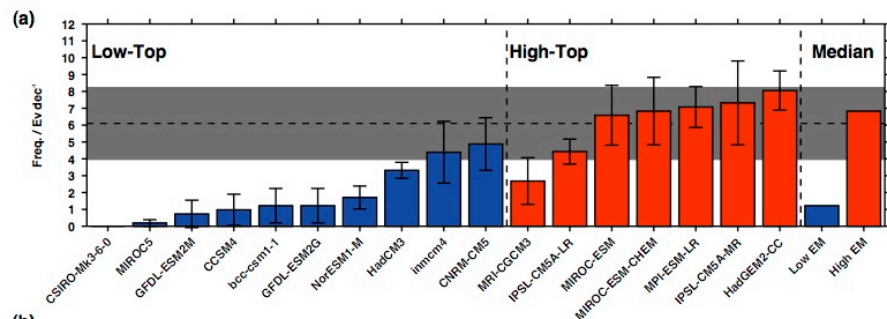
- Troposphere-stratosphere coupling is two-way with upward influence dominating
- Linkage from the troposphere to stratosphere mainly due to upward wave propagation and interaction of these waves with the stratospheric mean flow



# Mechanisms of Downward Stratospheric Modulation of the Tropospheric Circulation

- Non-local balanced response to a **given** stratospheric torque
  - Eliassen adjustment (Eliassen 1951)
  - Downward control (Haynes et al. 1991)
  - PV inversion (Hartley et al. 1998, Black 2002, Ambaum & Hoskins 2002)
- Wave behavior determined by **given** zonal-mean flow via index of refraction (e.g. Charney & Drazin 1961, Matsuno 1970)
  - Dissipation at critical layer (e.g. McIntyre & Palmer 1983)
  - Reflection (e.g. Perlwitz & Harnik 2003, Shaw et al. 2010)
  - Resonance (e.g. Tung & Lindzen 1979, Plumb 1981, Esler & Scott 2005)
- Alteration of planetary Rossby wave propagation within the troposphere in response to changed stratospheric basic state and enhancement of tropospheric annular mode response due to synoptic-scale eddies (e.g. Lorenz and Hartmann 2001, 2003, Wittman et al 2007)
- **Degraded representation of stratospheric processes in AGCMs affects simulated tropospheric climate and variability (Boville, 1984)**

# Charlton-Perez, A. J., and Coauthors, 2013: On the lack of stratospheric dynamical variability in low-top versions of the CMIP5 models.



## Low-top model ensemble

- very weak stratospheric variability on daily and interannual time scales.
- the frequency of major sudden stratospheric warming events is strongly underestimated by the low-top models
- Northern Annular Mode events are less persistent, leading to a shorter-lived tropospheric impact than in observations

# Lee and Black, 2014: The Structure and Dynamics of the Stratospheric Northern Annular Mode in CMIP5 Simulations

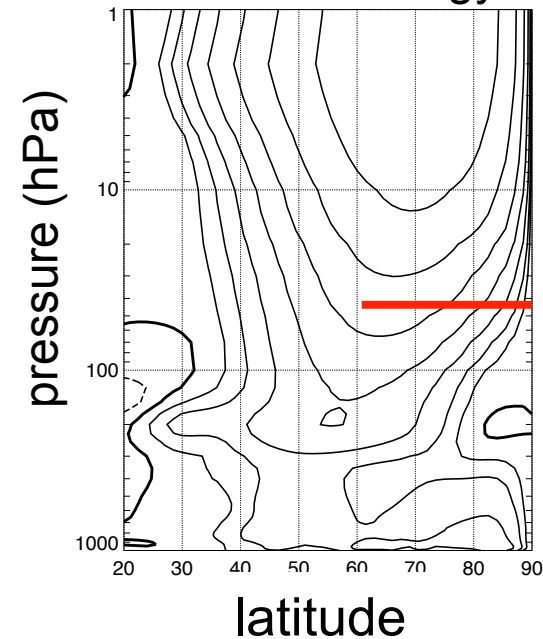
- The structure and dynamics of stratospheric northern annular mode (SNAM) events in CMIP5 simulations are studied, emphasizing (i) stratosphere–troposphere coupling and (ii) disparities between high-top (HT) and low-top (LT) models.
- Compared to HT models, LT models generally underrepresent SNAM amplitude in stratosphere, consistent with weaker polar vortex variability
- This difference does not carry over to the associated zonal-mean SNAM signature in troposphere, which closely resembles observations in both HT and LT models.

**Shaw, T. A., J. Perlwitz, and O. Weiner, 2014: Troposphere-stratosphere coupling: Links to North Atlantic weather and climate, including their representation in CMIP5 models**

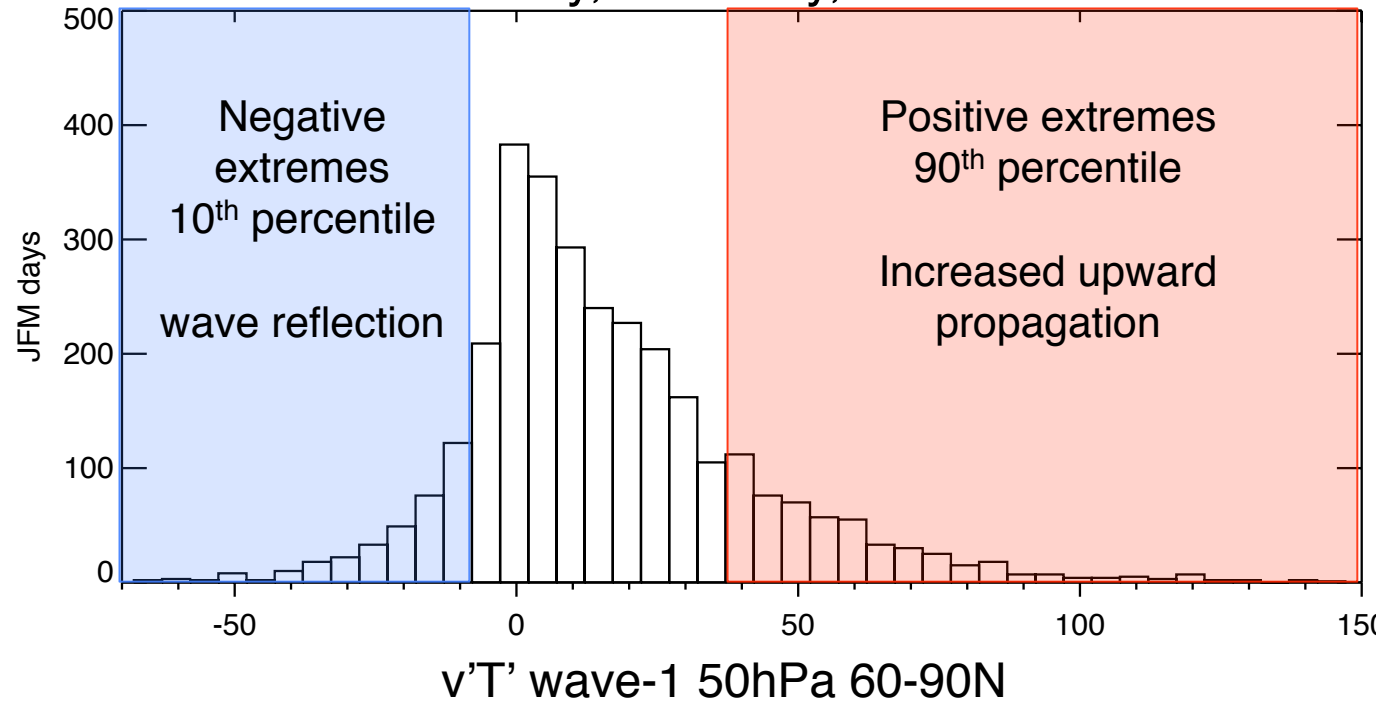
- Introduced new framework for model evaluation of wave coupling between the troposphere and stratosphere based on heat-flux extremes in the lower stratosphere
- No pre-selection of low-top versus high top models
- **Main take home message: Simple comparison between low and high-top model not sufficient to understand structural tropospheric climate biases related to stratospheric representation in climate models**

# JFM Polar Cap Heat Flux distribution at 50hPa in ERA interim

Wave-1  $\overline{v'T'}$   
JFM climatology

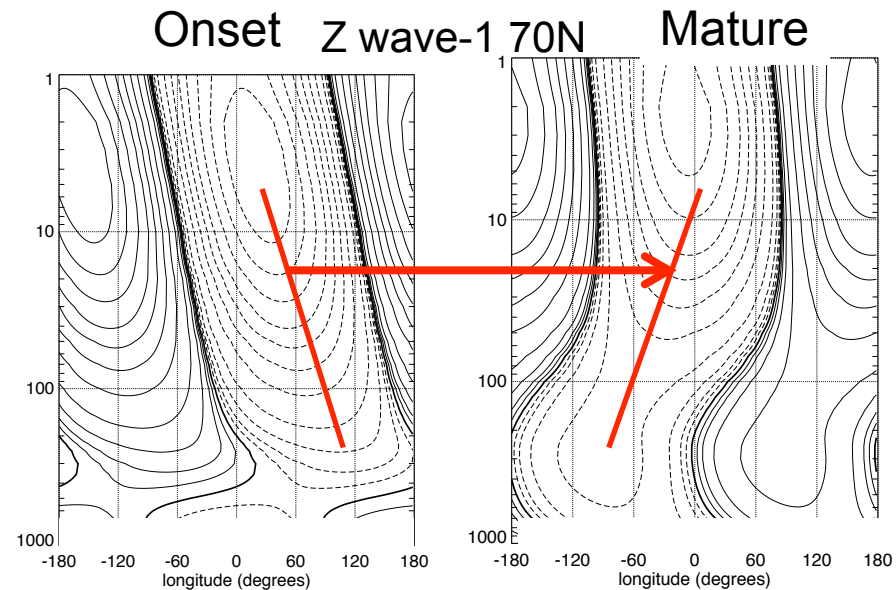
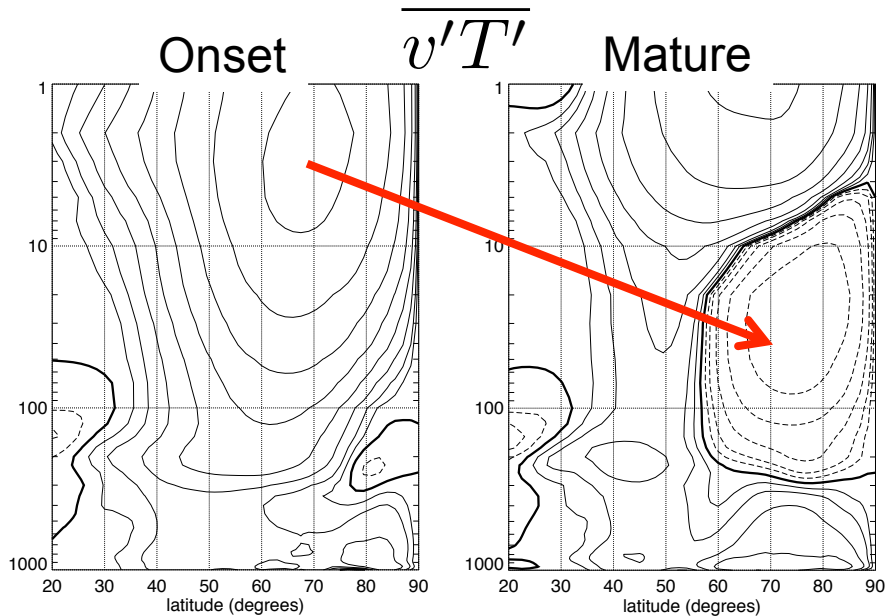
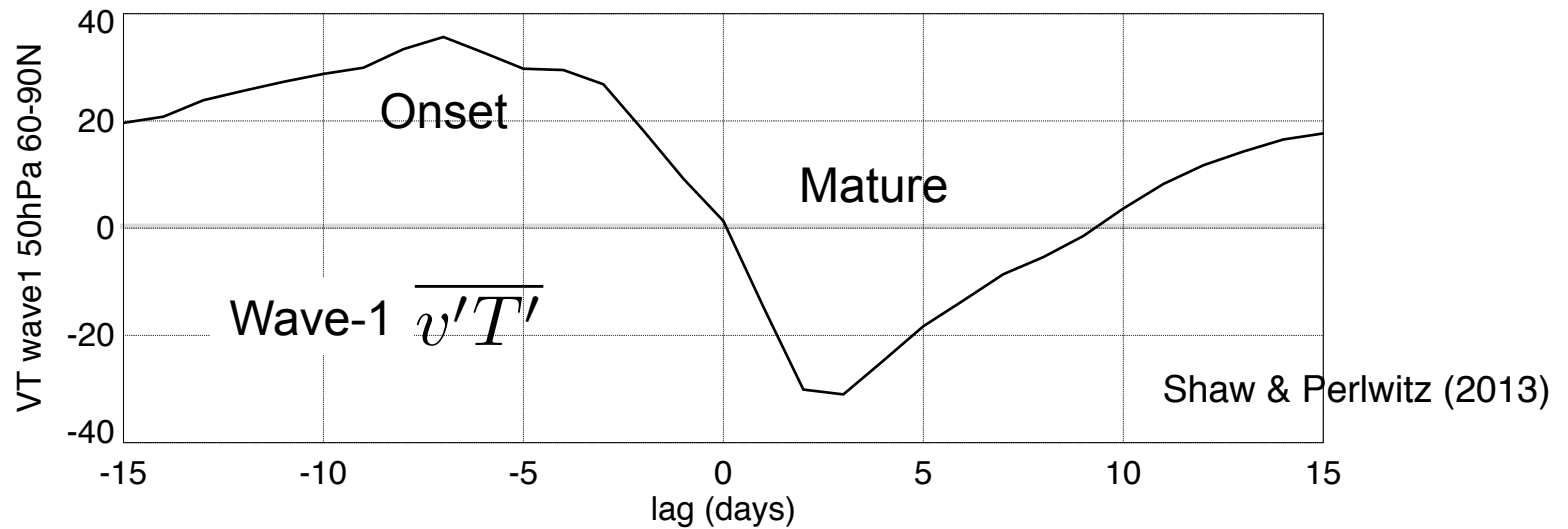


January, February, and March



ERAinterim data  
1979-2012

# Stratospheric life cycle for extreme negative heat flux values



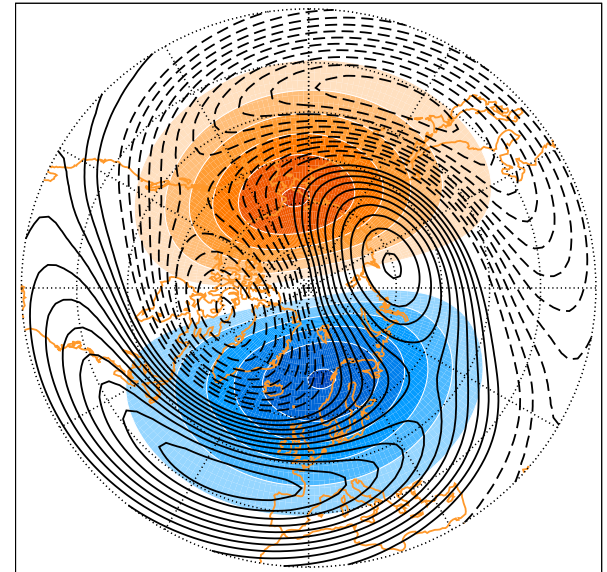
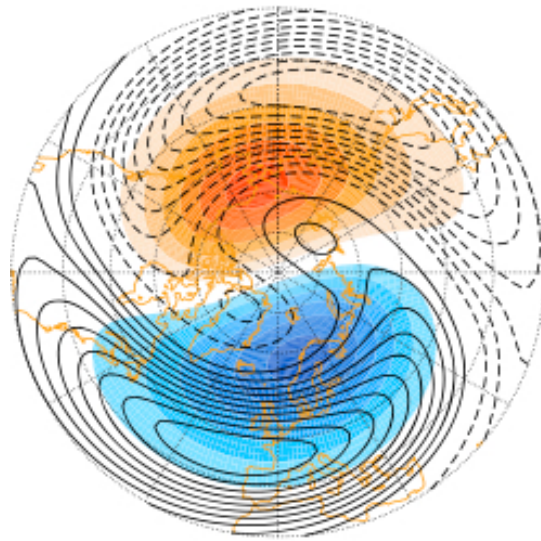


# Extreme stratospheric heat flux events associated with high-latitude wave-1 signal in the troposphere

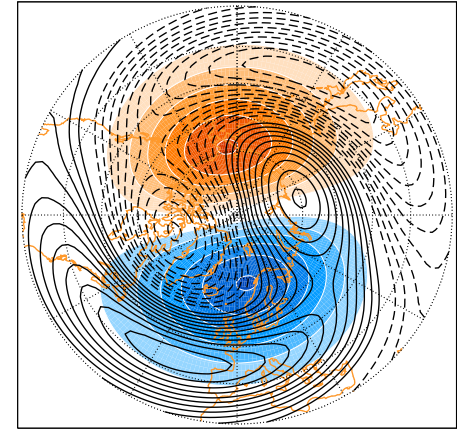
climatology

Negative extremes

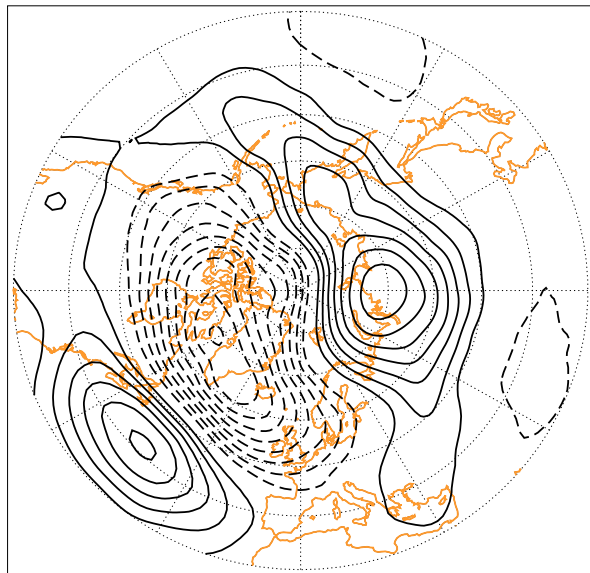
**Z wave-1**  
**10hPa (color) and**  
**500hPa (black)**



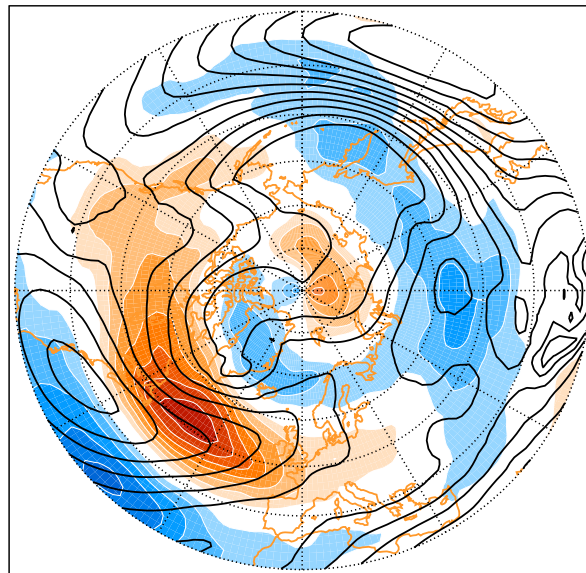
# Extreme negative heat flux events associated with positive NAO-like anomalies



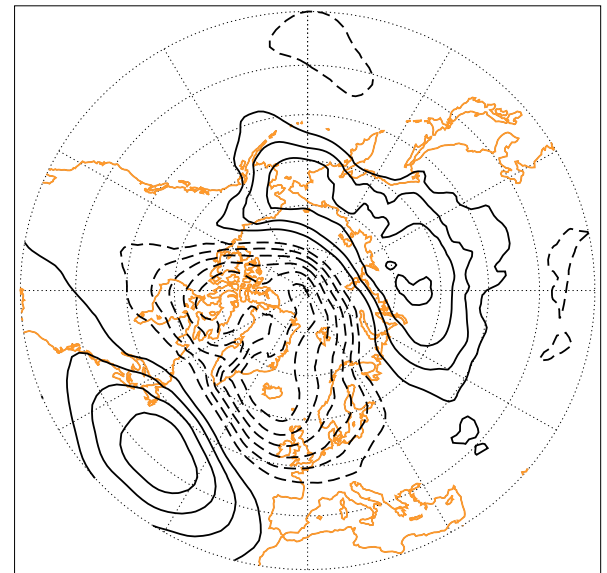
Z' 500



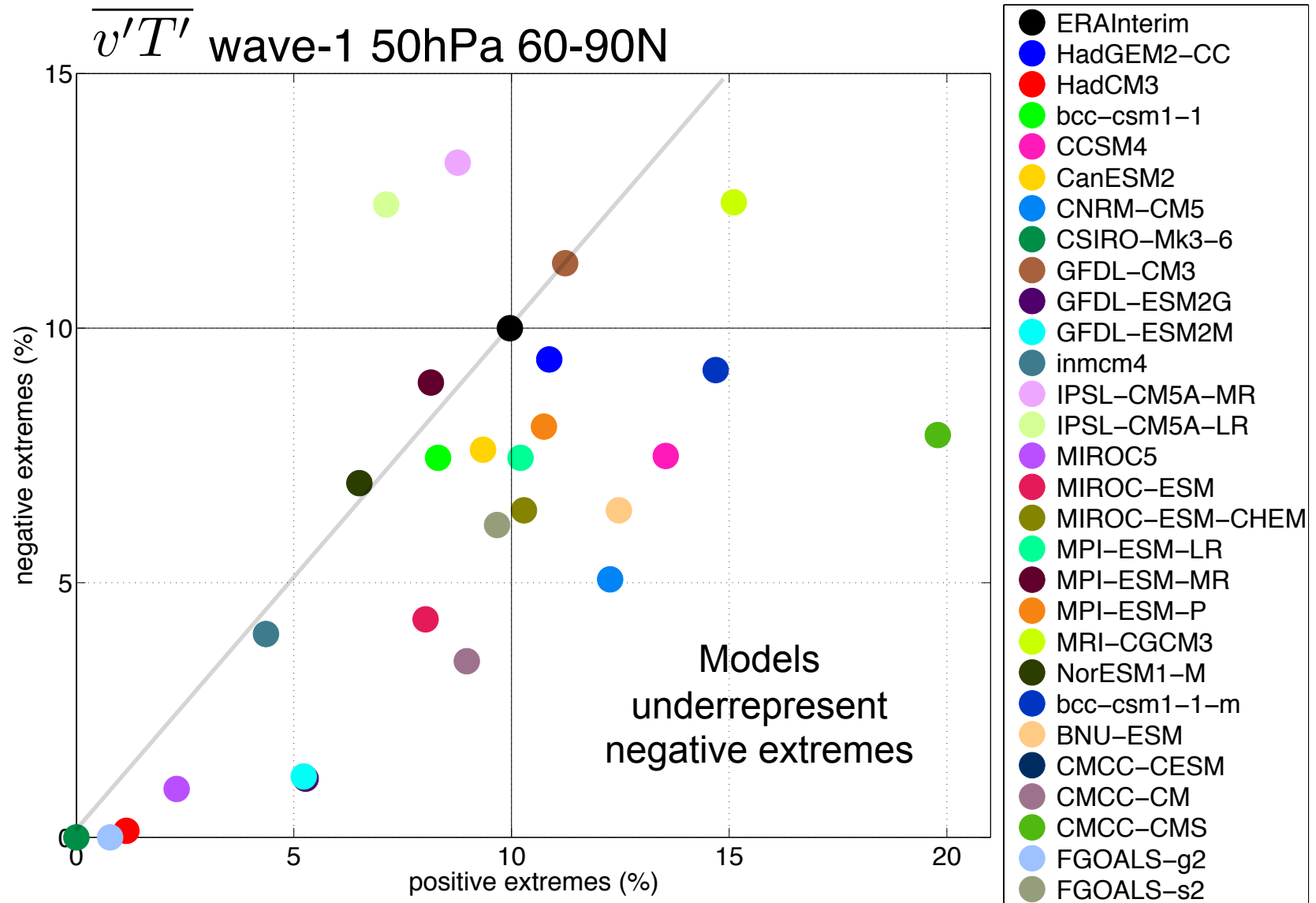
U 500 hPa



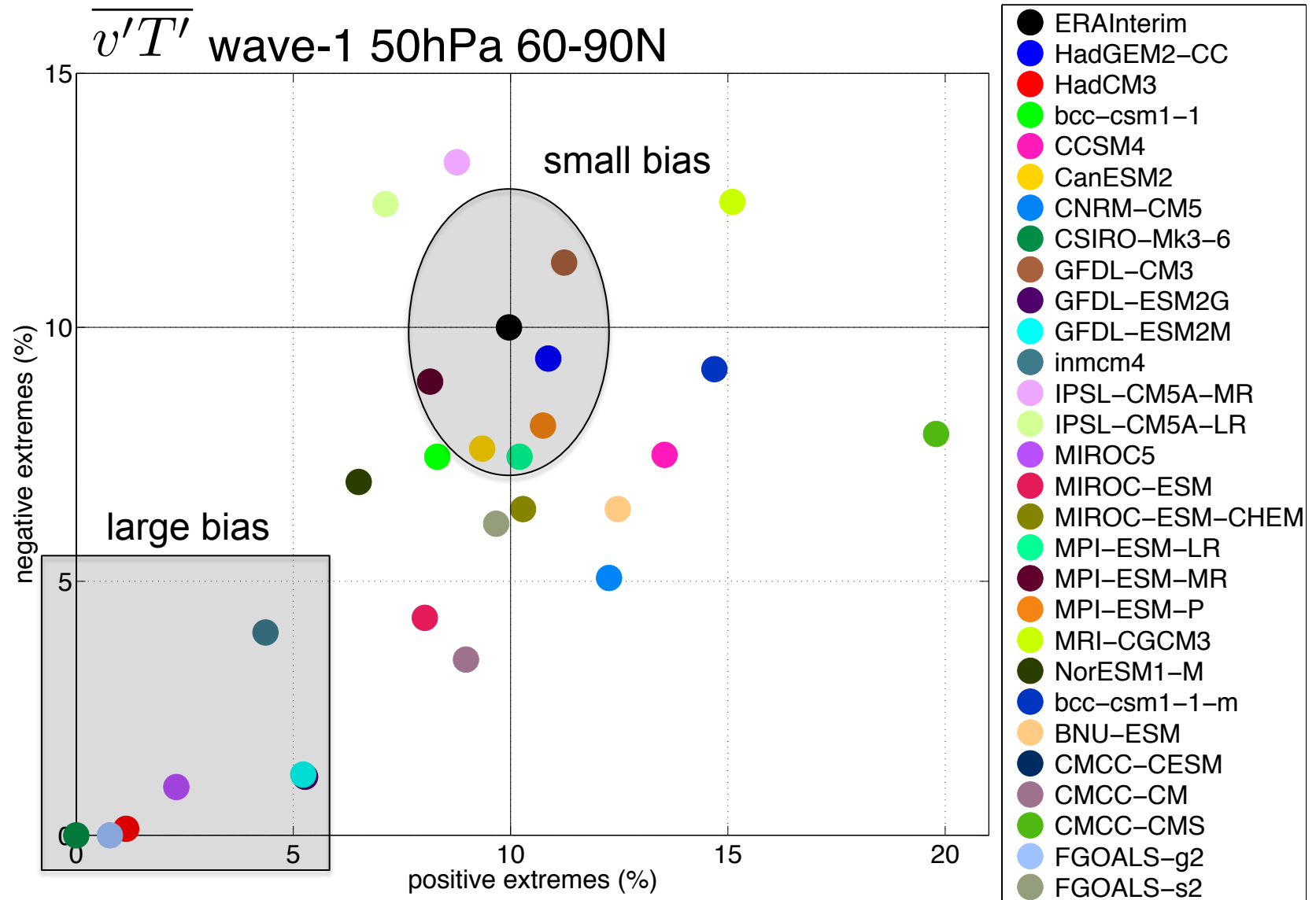
mslp



# Do models represent wave coupling properly?

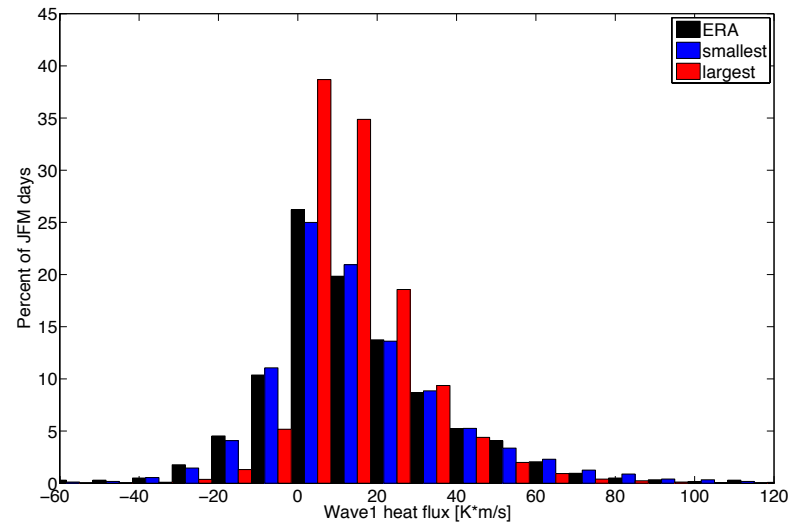


# Model groups by stratospheric bias

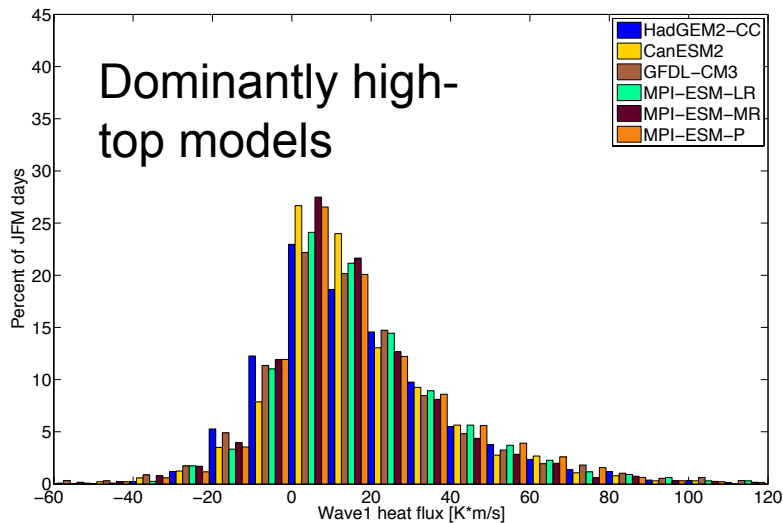


# Model groups by stratospheric bias

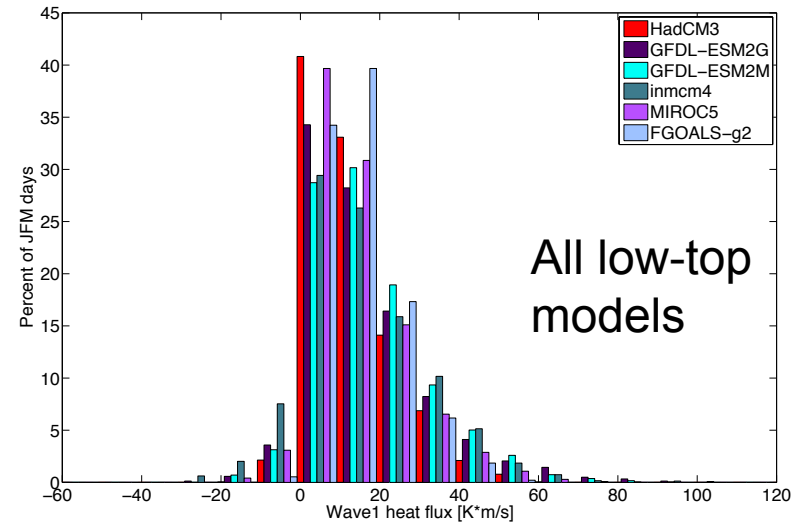
Wave-1  $\overline{v'T'}$   
50hPa 60-90N



Small bias



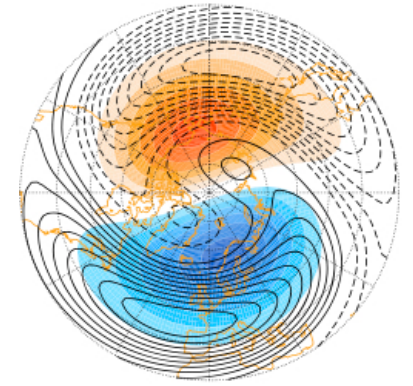
Large bias



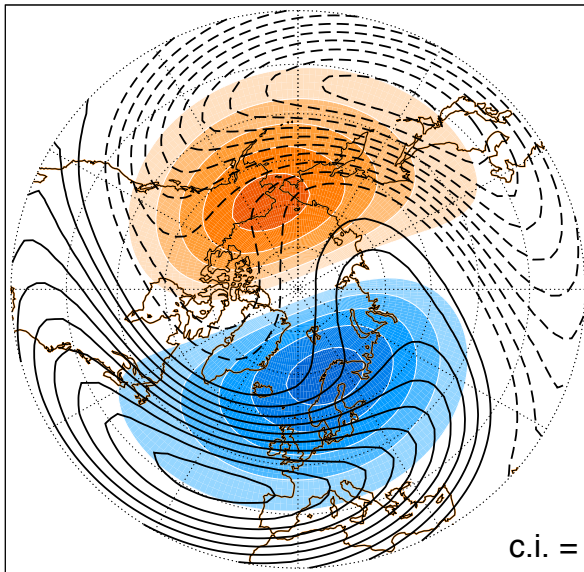


# Stratospheric bias linked to climatology bias of planetary wave structure in the troposphere

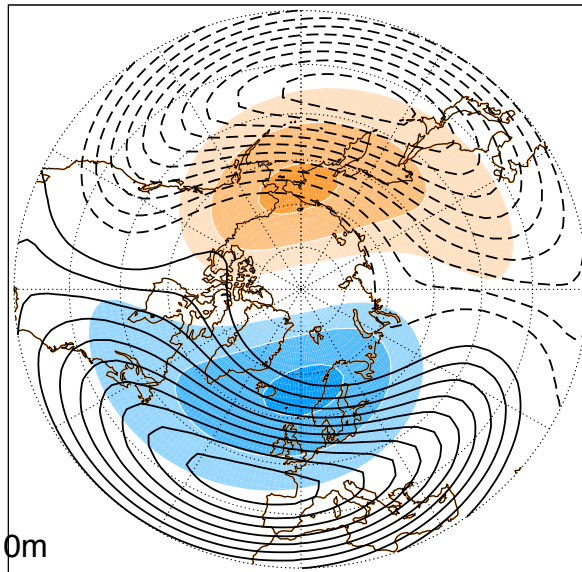
Era interim Climo



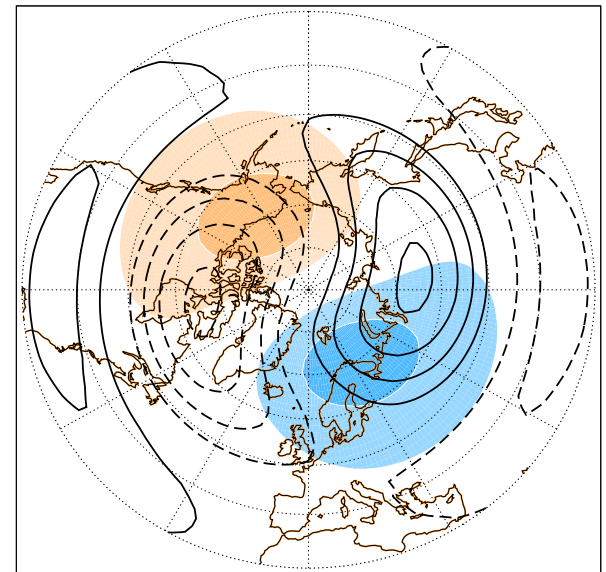
Small bias



Large bias



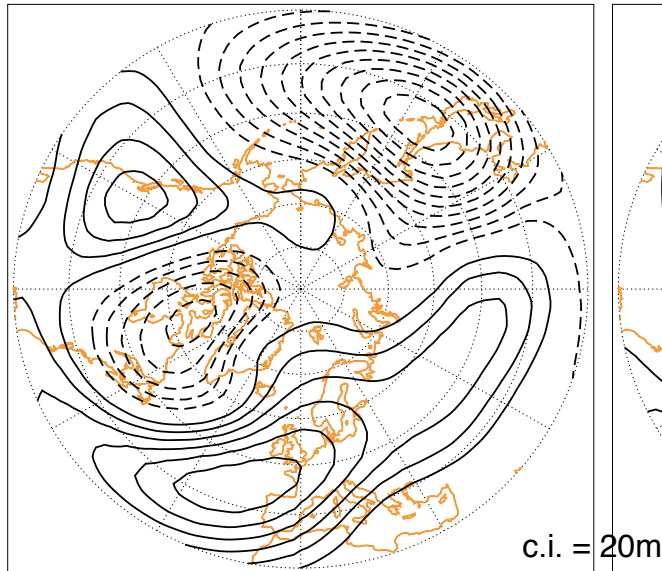
Difference



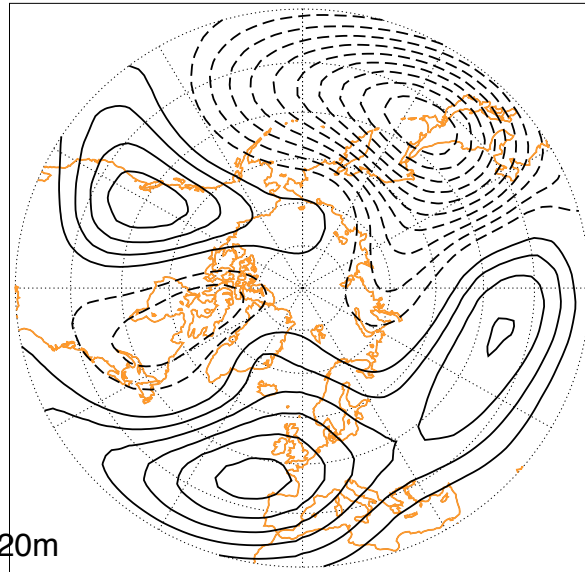
Wave 1 10hPa (color) and 500hPa (black)

# Stratospheric bias linked to climatology bias of wave structure in the troposphere for $Z' 500$

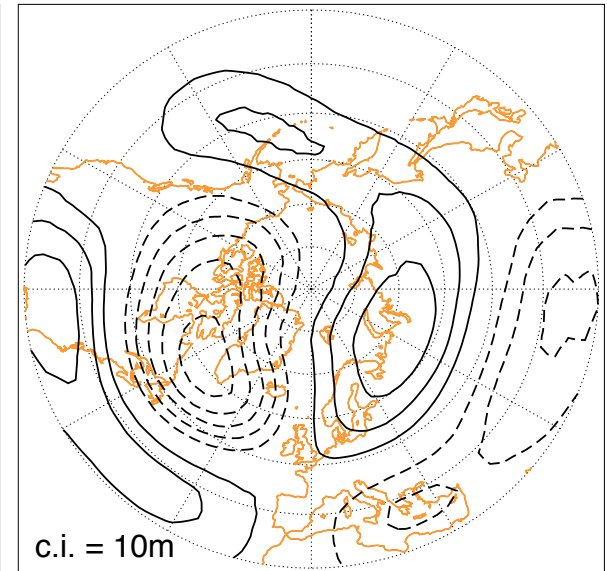
Small bias



Large bias

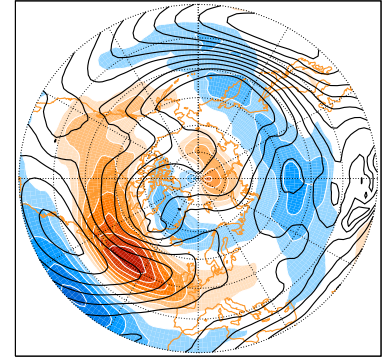


Difference

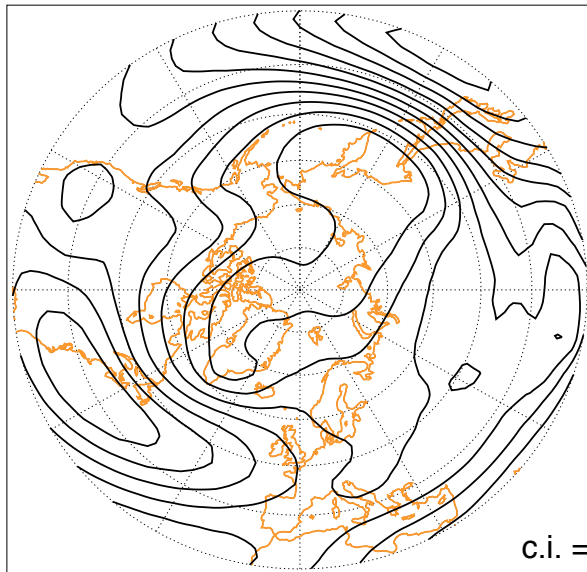


# Realistic stratospheric eddy heat flux linked to more realistic Atlantic jet structure (U 500hPa)

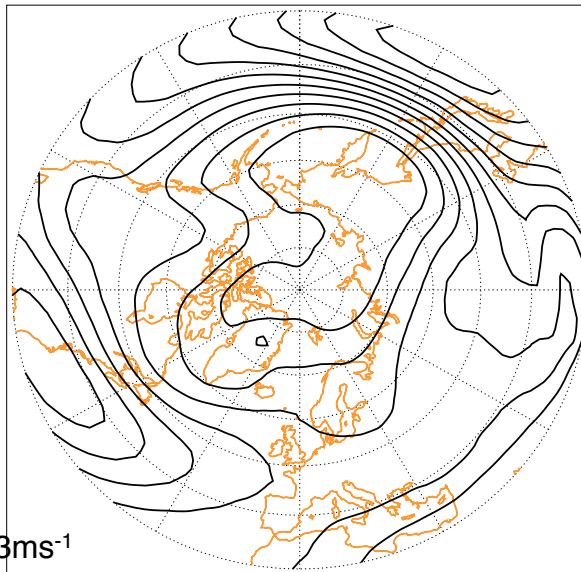
EraInterim



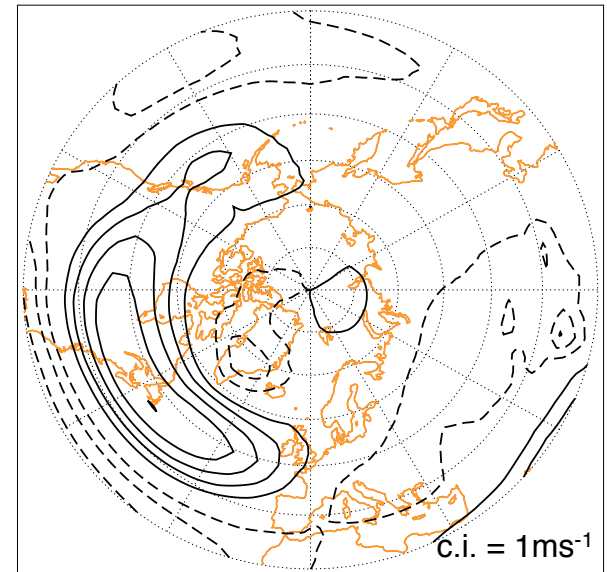
Small bias



Large bias

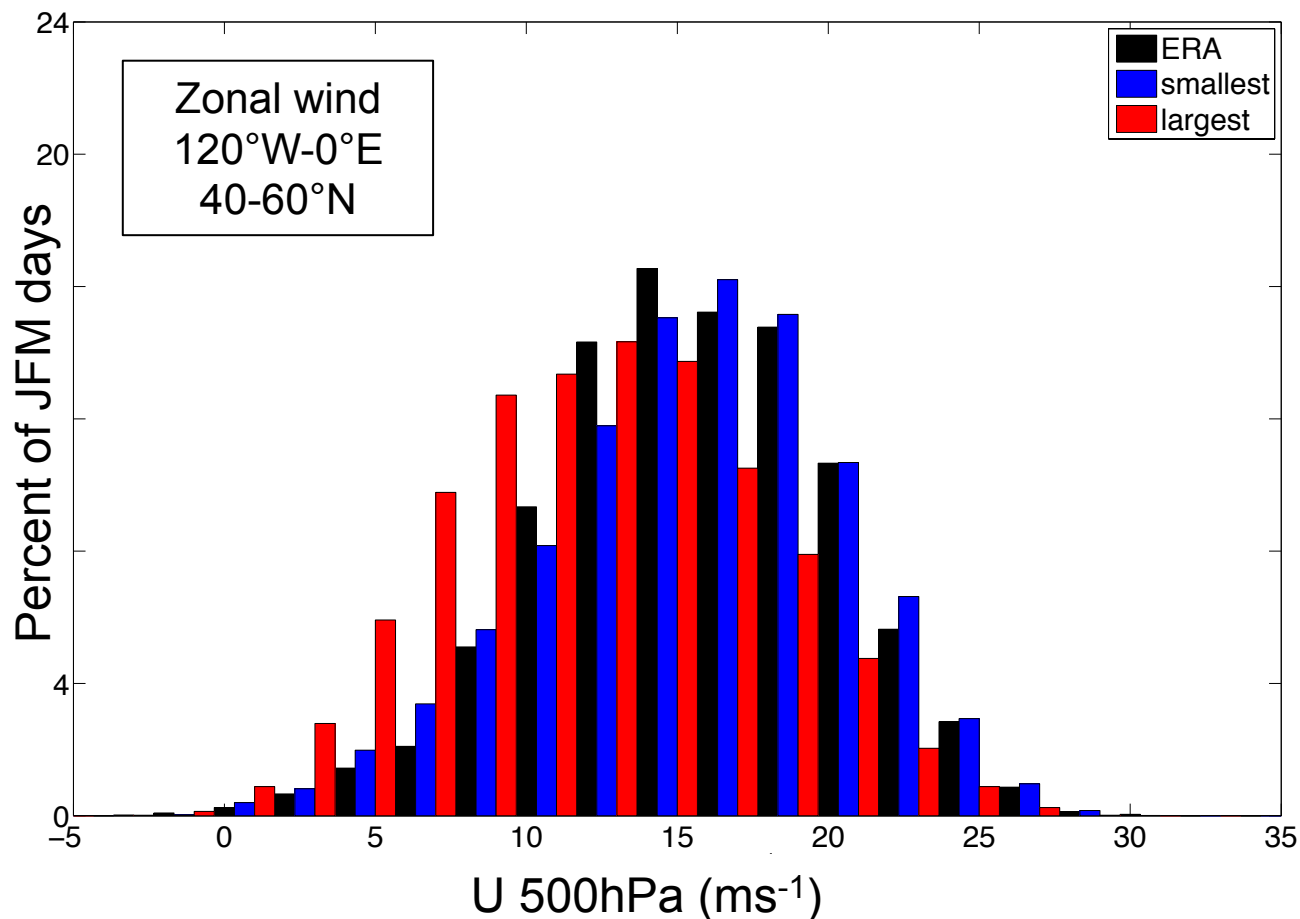


Difference

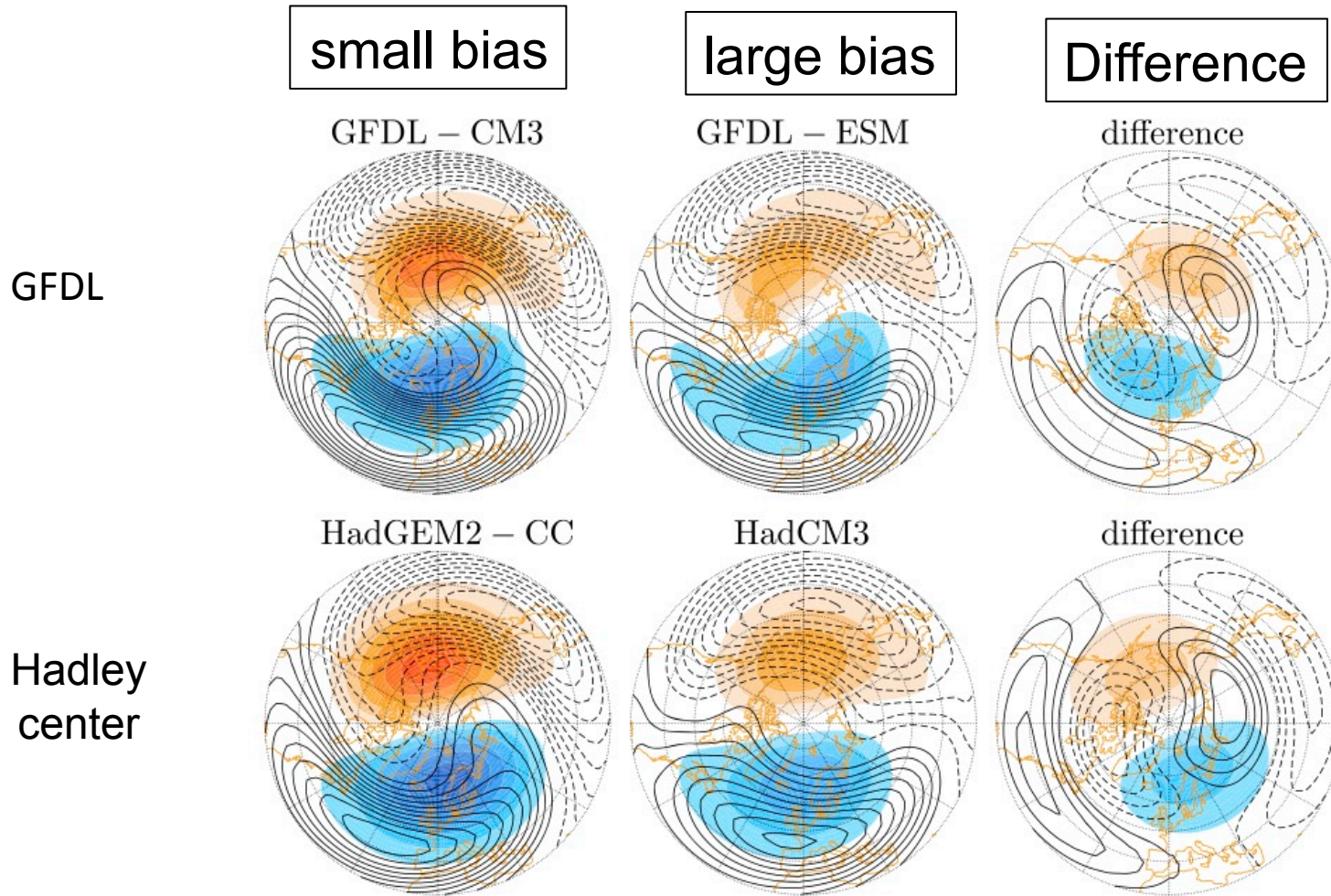
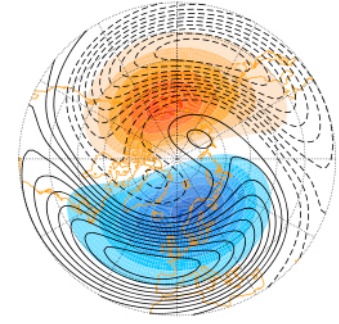




# Realistic stratospheric heat flux linked to more realistic variability of Atlantic jet stream

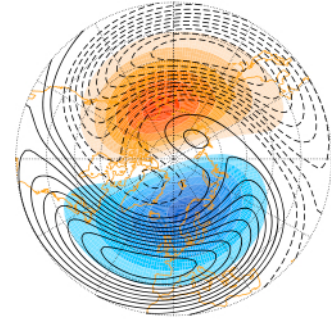


# Model Family Comparison of Wave 1 Climatology at 500 and 10 hPa for small and large bias

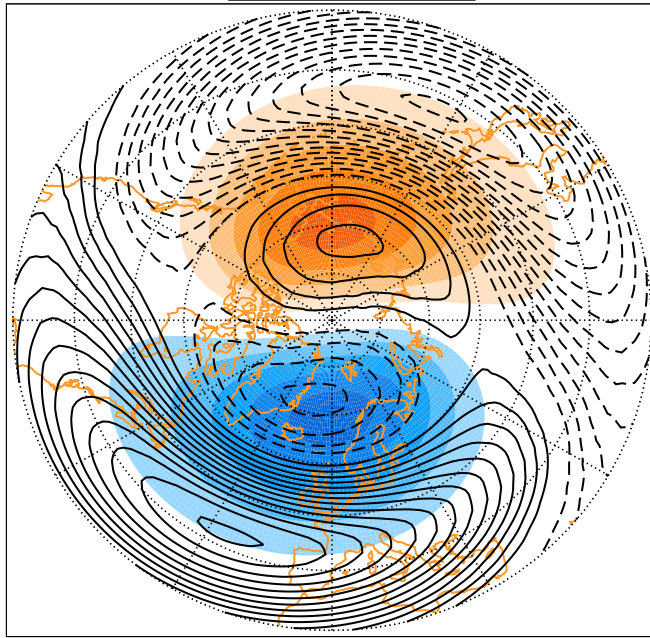


Wave 1 10hPa (color) and 500hPa (black)

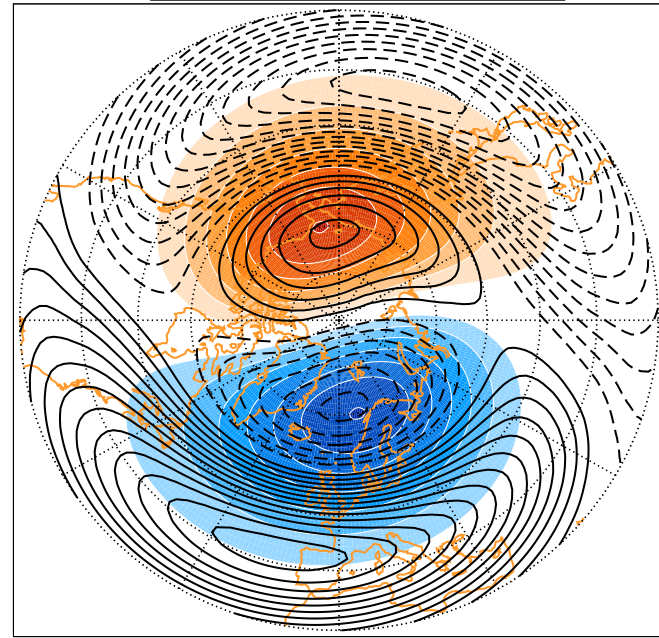
# CMIP 5 models with exaggerated wave connection



CCSM4



bcc-csm1-1-m



- Small phase tilt with height indicates direct interaction with model lid (Shaw & Perlwitz 2010, Sassi et al. 2010).

# Summary

- CMIP5 models that do not properly represent the distribution of extreme stratospheric heat flux events exhibit a biased climatological planetary wave structure in the Northern Hemisphere troposphere
  - Consistent with Boville (1984) and Shaw & Perlwitz (2010)
  - A well-resolved stratosphere leads to a more accurate planetary wave structure and Atlantic jet stream in the troposphere
- Models without a proper representation of stratospheric dynamics may be missing an amplifying effect on both the negative NAO phase as well as positive NAO phase due to various coupling mechanisms between troposphere and stratosphere.
- Simple comparison between low and high-top models not sufficient for understanding structural tropospheric climate bias related to stratospheric biases